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(NASA-Case-LAR-13257-1) A SYSTEM FOR  
CONTROLLING THE OXYGEN CONTENT OF A GAS  
PRODUCED BY COMBUSTION Patent Application  
(NASA) 10 p HC A02/MF A01 CSCI 21B

N84-32447

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G3/25 21983



NASA CASE NO. LAR-13,257-1

PRINT FIG. 1

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S.N. 633,178  
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LaRC

AWARDS ABSTRACT

LAR 13257-1

A SYSTEM FOR CONTROLLING THE OXYGEN CONTENT OF A  
GAS PRODUCED BY COMBUSTION

The invention relates to a method and apparatus for controlling the oxygen content of a gas produced by combustion.

The invention consists essentially of a combustion chamber 10 into which air,  $\text{CH}_4$  and  $\text{O}_2$  flow. The gas produced by the combustion in chamber 10 flows into a test section 17. The partial pressure of  $\text{O}_2$  in the gas in test section 17 is compared to the partial pressure of  $\text{O}_2$  in reference air by means of an  $\text{O}_2$  sensor 22. If there is a difference in partial pressure an error signal is produced at the output of control circuit 25. The error signal is applied to a solenoid valve 15 which regulates the flow of  $\text{O}_2$  in chamber 10 to thereby reduce the error signal to zero. When the error signal is zero the oxygen content in test section 17 is the same as the oxygen content of air. The calibration air supplied through valve 27 and the voltmeter 28 are for the purpose of measuring the cell constant of sensor 22 when air is applied to both sides of the sensor. This measured cell constant is set into a potentiometer 29 and subtracted from the output of sensor 22 to produce the error signal when the gas from test section 17 is applied to sensor 22.

The details of sensor 22 are shown in FIG. 2. The chamber 35 was modified such that the gas from the test section is flushed out of the chamber immediately after arriving thereby making the response time of the sensor extremely short.

The novel feature of the invention appears to lie in the overall combination of elements to provide a device for controlling the oxygen content of a combustion gas such that it is the same as that of air. Also, the modification of the  $\text{O}_2$  sensor to make it have a fast response time appears to be novel.

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A SYSTEM FOR CONTROLLING THE OXYGEN CONTENT OF A  
GAS PRODUCED BY COMBUSTION

ORIGIN OF THE INVENTION

5       The invention described herein was made by employees of  
the United States Government and may be manufactured and  
used by the Government for governmental purposes without the  
payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

10       The invention relates to the control of the amount of a  
specific gas in a combustion product gas and more  
specifically concerns the control of the amount of oxygen in  
a combustion product gas.

15       At Langley Research Center in Hampton, Virginia, there  
is an 8-Foot High Temperature Tunnel for testing aircraft  
engines. In this facility methane gas is burned in air  
under pressure and the products of the combustion are  
expanded through an axisymmetric, conical contoured nozzle  
with an exit diameter of 8-feet to produce a nominal Mach 7  
20       flow in the test section. However, because of the reduced  
oxygen content in the test medium, the facility is not  
suitable for air-breathing-propulsion testing. If the  
oxygen content in the test medium were to be increased to  
accommodate air-breathing-propulsion testing, it is very  
25       important that the oxygen content be equivalent to the  
oxygen content of air. Too much oxygen may damage the  
engine, and too little oxygen will result in reduced  
impulse. Also, because of limited run time of the facility  
(as little as 20 seconds for some conditions), a  
30       fast-response (response time of less than one percent of the  
tunnel run time) oxygen monitoring and control system is  
required.

35       It is an object of this invention to maintain the  
oxygen content of a test medium equal to the oxygen content  
of a selected gas.

      Another object of this invention is to maintain the  
oxygen content of gases produced by combustion equal to that  
of air.

A further object of this invention is to compare the oxygen content of the gas products of combustion with the oxygen content of air and to reduce the difference to zero.

5 Still another object of this invention is to provide a device having an extremely short response time for comparing the oxygen contents of two gases.

Other objects and advantages of this invention will become apparent hereinafter in the specification and  
10 drawings.

#### SUMMARY OF THE INVENTION

The invention includes a combustion chamber into which a mixture of gases including  $O_2$  flows. The mixture of gases is burned in the combustion chamber to produce a product  
15 gas. The purpose of this invention is to regulate the flow of  $O_2$  into the mixture so that content of  $O_2$  in the product gas is equal to the content of  $O_2$  in air. This is done by comparing the partial pressure of  $O_2$  in the product gas with the partial pressure of  $O_2$  in air to produce an error  
20 signal. This error signal is used to regulate the flow of  $O_2$  into the combustion chamber to make the error signal equal to zero thereby keeping the  $O_2$  content of the product gas equal to the  $O_2$  content of air.

#### BRIEF DESCRIPTION OF THE DRAWINGS

25 FIG. 1 is a block diagram of the invention; and  
FIG. 2 is a schematic drawing of the  $O_2$  sensor shown in FIG. 1.

#### DETAILED DESCRIPTION OF THE INVENTION

Turning now to the embodiment of the invention selected  
30 for illustration the number 10 in FIG. 1 of the drawings designates a combustion chamber. Air under pressure flows through a valve 11 and a flowmeter 12 into combustion chamber 10;  $CH_4$  under pressure flows through a valve 13 and a flowmeter 14 into combustion chamber 10; and oxygen under  
35 pressure flows through a solenoid controlled valve 16 and a flowmeter 16 into combustion chamber 10. The mixture of gas flowing into combustion chamber 10 is burned and the product gas of the combustion flows into a test section 17. A sample of the gas in test section 17 flows through a valve  
40 18, a compressor 19, a flowmeter 20 and a heater 21 into one

side of an  $O_2$  sensor 22. Compressor 19 is required to pressurize the sample of gas from test section 17. Reference air under pressure flows through a valve 23 and a flowmeter 24 to the other side of the  $O_2$  sensor 22. If there is a difference in the oxygen contents of the gas from the test section and reference air,  $O_2$  sensor 22 will produce a signal that is adjusted by a control circuit 25 and then applied to solenoid valve 15. This adjusted signal called an error signal will change the flow of  $O_2$  into the combustion chamber 11 which in turn will change the oxygen content of the gas in test section 17. When the oxygen contents of the gas in test section 17 and air become equal the adjusted signal at the output of control circuit 25 becomes zero. Hence, if the response of the system is fast the oxygen content of the gas in the test section 17 will be the same as that of air. If the difference in the oxygen contents of the gas in test section 17 and air exceeds a predetermined amount, visual and audio alarms are given by a visual audio alarm device 26 to signal that the system should be shut down.

The  $O_2$  sensor 22 is shown in more detail in FIG. 2. The sensor includes a high temperature,  $Y_2O_3$  stabilized  $ZrO_2$  ceramic electrolyte disc 30 coated with porous platinum electrodes 31 and 32. The platinum electrodes 31 and 32 are porous enough to permit ready diffusion of gases through them. A practical relationship between the sensor voltage output  $E$  across electrodes 31 and 32 is given by the following equation:

$$E = AT \ln \left( \frac{P_1}{P_2} \right) + C(P) \quad (1)$$

where  $A$  is a mathematical constant,  $T$  is the  $ZrO_2$  disc temperature,  $P_1$  is the partial pressure of oxygen on electrode 31,  $P_2$  is the partial pressure of oxygen on electrode 32 and  $C(P)$  is the cell constant determined by calibration with known gas mixtures at known pressures.

The  $ZrO_2$  disc 30 and electrodes 31 and 32 are enclosed in a cylindrical enclosure 33 with disc 30 dividing enclosure 33 into two cavities 34 and 35. Electrode 31 is exposed to the gas inside cavity 34 and electrode 32 is

exposed to the gas inside cavity 35. The gas from test section 17 is introduced into cavity 35 and reference air is introduced into cavity 34 through valve 23. The test  
5 section gas in cavity 35 is pumped out through a flowmeter 36 by means of a pump 37 to keep the test section gas moving through cavity 35. Cavity 35 has a volume of less than  $1 \text{ cm}^3$  with a 0.5 mm circumferential slot opening 38 approximately 0.5 mm from disc 30. Consequently, the gas in  
10 cavity 35 is flushed out of the cavity almost immediately after entering the cavity by the gas entering the cavity. The test section gas in cavity 35 is pumped out through a flowmeter 36 by means of a pump 37 to keep the test section gas moving through cavity 35. As a result, the response  
15 time of the system is greatly decreased.

The voltage E produced across electrodes 31 and 32 is extremely sensitive to disc 30 temperature. Hence, it is important that the temperature of disc 30 be maintained at a high level of approximately  $843^\circ\text{C}$ . To maintain the  
20 temperature at  $843^\circ\text{C}$ , a NiCr/NiAl thermocouple 39 monitors the temperature of disc 30. The output of thermocouple 39 is compared with a set voltage in a voltage controller 40 to produce an error signal which is used by voltage controller 40 to produce a voltage across a heating coil 41 to maintain  
25 disc 30 at a temperature of approximately  $843^\circ\text{C}$ . In order to avoid an increase in sensor response time caused by the cooling effect of the lower temperature gas from test section 17 the gas is heated to about  $843^\circ\text{C}$  by heater 21 before it reaches the  $\text{O}_2$  sensor 22.

It is apparent from equation (1) that when the partial pressures of the gas from test section 17 and reference air are compared the output E of  $\text{O}_2$  sensor 22 will not be directly proportional to the difference of the two partial pressures. The reason is that the cell constant  $C(P)$  is not  
35 equal to zero. Hence,  $C(P)$  must be determined. To do this valve 18 is closed and calibration air under pressure is applied through a valve 27, flowmeter 20, and heater 21 to  $\text{O}_2$  sensor 22. Consequently, the partial pressure of calibration air is compared to the partial pressure of  
40 reference air and if the flow rates of flowmeters 20 and 24

are the same the output E of  $O_2$  sensor 22 will be C(P). This output is measured by a voltmeter 28. Then the slider of a potentiometer 29, with a voltage V applied to it, is  
5 adjusted to apply C(P) to control circuit 25. Control circuit 25 subtracts the output of potentiometer 29 from the output of  $O_2$  sensor 22 and then amplifies the difference to produce an error signal that is applied to solenoid valve 15 to change the flow of oxygen into chamber 10, thereby  
10 forcing the error signal to zero. This ensures that the oxygen content of the gas in test section 17 is the same as the oxygen content of air.

The advantages of this invention are that it provides a fast response, simple straight forward means for maintaining  
15 the oxygen content of a combustion product gas the same as the oxygen content of a different gas, for example, air.

It is to be understood that the form of the invention herewith shown and described is to be taken as a preferred embodiment. Various changes may be made without departing  
20 from the invention. For example, if an  $O_2$  sensor can be found in which  $C(P) = 0$ , valve 27, voltmeter 28 and potentiometer 29 can be eliminated; or if C(P) is known this value can be set into potentiometer 29 and valve 27 and voltmeter 28 can be eliminated. Also, the combustion gas  
25 can be different from that shown and the gas to which the combustion product gas is compared can be a gas other than air.

What is claimed is:

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LAR 13257-1

A SYSTEM FOR CONTROLLING THE OXYGEN CONTENT OF A  
GAS PRODUCED BY COMBUSTION  
ABSTRACT OF THE DISCLOSURE

5 A mixture of air,  $\text{CH}_4$  and  $\text{O}_2$  is burned in a combustion  
chamber 10 to produce a product gas in test section 17. The  
 $\text{O}_2$  content of the product gas is compared with the  $\text{O}_2$   
content of reference air in an  $\text{O}_2$  sensor 22. If there is a  
difference an error signal is produced at the output of  
10 control circuit 25 which by the means of a solenoid valve 15  
regulates the flow of  $\text{O}_2$  into combustion chamber 10 to make  
the error signal zero. Hence, the product gas in test  
section 17 has the same oxygen content as air.

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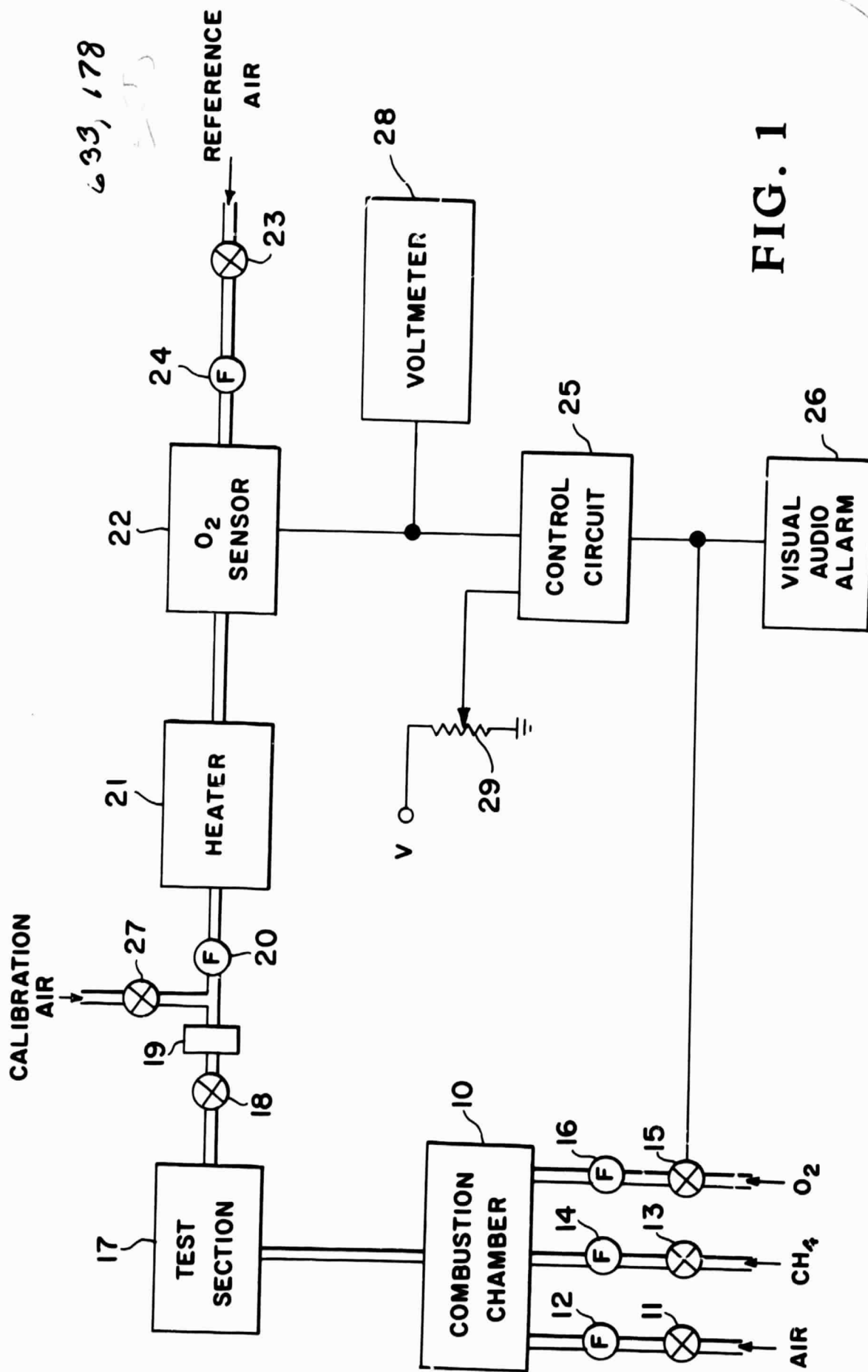


FIG. 1

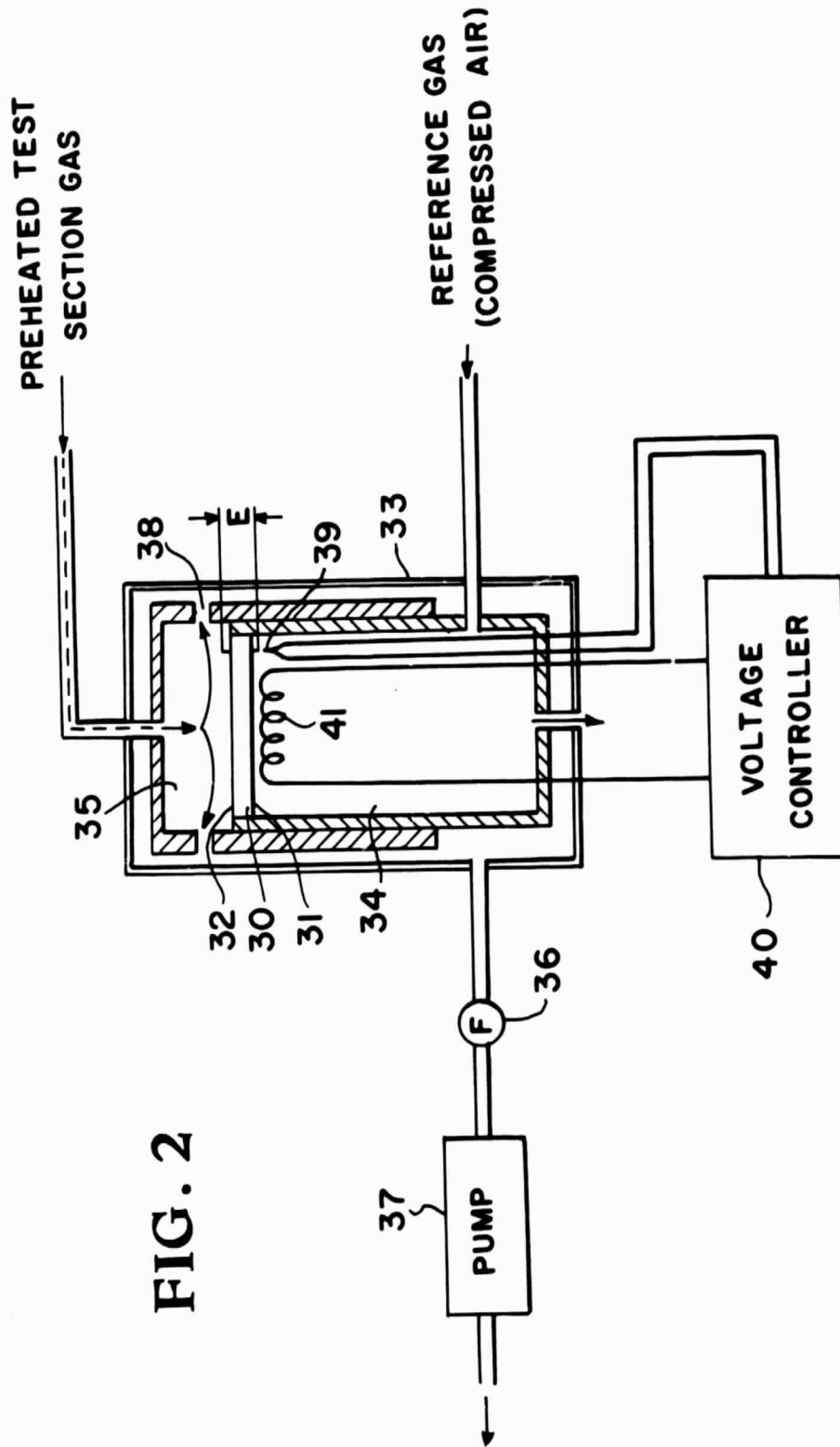


FIG. 2